

Good morning everyone, the event is going to start in just a few minutes, so please silence your cell phones and take a seat, thank you. Okay, welcome to today's press conference brought to you by the National Science Foundation. Thank you for joining us today. My name is Amanda Greenwell, I am the head of the National Science Foundation office of set up in public affairs. I would like to introduce today's distinguished panel, director of the National Science Foundation, Sheppard Dolman, the event horizon telescope director of the Center for after physics, Harvard, and Smithsonian, the event councilmember, and the associate professor of astronomy at the University of Arizona, Avery is a member of the telescope board and chair at the perimeter of the University of Waterloo. A professor of theoretical physics at the University of Amsterdam and she coordinates the DHT multilayered length -- multilayered --

Good morning, thank you for joining us at this historic moment. I would like to give a special welcome to the director of the White House office of science and technology policy. And from the national science board, the current chair, Diane and former chair, Maria. Today, the event horizon telescope project will announce findings that will transform and enhance our understanding of black holes. As an astrophysicist, this is a thrilling day for me. Black holes have captivated the imaginations of scientists and the public for decades. In fact, we have been studying black holes so long, that sometimes it is easy to forget that none of us have actually seen one. Yes, we have simulations and illustrations. Thanks to instruments supported by the National Science Foundation, we have detected binary black holes, merging deep in space. We have observed the episodic transfer of matter from companion stars onto black holes. Some massive black holes create particles and radiation. We have spotted the subatomic materials they can fling across millions of light-years, but we have never actually seen the event horizon, that point of no return after which nothing, not even light can escape a black hole. How did we get here? Through the imagination and dedication of science around the world. Willing to collaborate to achieve a huge goal. To a large pool of international facilities, and through long-term financial commitments from NSF and other funders willing to take a risk and pursuits of an enormous potential payoff. Without international collaboration, among facilities, the contributions of dozens of scientists and engineers and sustained funding, the event horizon project would have been impossible. No single telescope on earth has the sharpness to create an un-blurred definitive image of the black hole. This team did what all good researchers do, they innovated. More than five decades ago, other NSF funded researchers helped lead the development of very long baseline interferometry, which increases the telescope's capabilities. This team took that concept to a global scale. Connecting to the scopes to create a virtual array, the size of the earth itself. This was a huge task, one that involved overcoming numerous technical difficulties. It was an endeavor so remarkable that NSF has invested 28 million dollars in more than a decade, joined by many other organizations in our support, as these researchers shaped their idea into reality. I believe what you are about to see will demonstrate an imprint on people's memories. The event horizon project shows the power of collaboration, convergence, and shared resources, allowing us to tackle the universes biggest mysteries. Now I'm going to hand over this to our distinguished panel.

[Applause]

Thank you, black holes are the most mysterious objects in the universe, they are cloaked by an event horizon that prevents even light from escaping, and yet the matter that falls onto the event horizon is superheated so before it passes through, it shines very brightly. We now believe that supermassive black holes, billions times the size of our sun, and because they are so small that we have never seen one, we know they can outshine the combined starlight of all the constituent stars in the galaxy. The best idea we have of what they can look like come from simulations like this. The gas that is superheated lights up a ring of light where photons orbit the black hole, and the interior of that is a dark patch that prevents light from escaping. The event horizon telescope project is dedicated to the idea that we can make an image of this blackhole, we can set a ruler across this shadow feature and test Einstein's theory. It also allows access to a region of the universe we can study precisely the energetics and how black holes dominate the galaxies. To do this, we worked for over a decade to link telescopes around the globe to make the earth-sized virtual dish. The telescope achieves the highest resolution possible from the surface of the earth, it is equivalent to be able to read the date on a quarter in Los Angeles when we are standing here in Washington DC. In April 2017, all the dishes swiveled, turned, and stared at the galaxy 55 million light-years away, it is called M 87. There is a supermassive black hole at its core, and we are delighted to be able to report to you today that we have seen what we thought was unsuitable. We have seen and taken a picture of a black hole. Here it is.

[Applause]

This is a remarkable achievement, what you are seeing here is the last photons orbit, what you are seeing is evidence of an event horizon, by laying a ruler across this blackhole, we now have visual evidence for a blackhole, we now know that a black hole that weighs 6.5 billion times what our sun does, it is the strongest evidence that we have to date for the existence of black holes. It is also consistent to the precision of our measurements with Einstein's predictions. The bright path tells us that the material moving around the black hole is moving at light speed, which is also consistent with our simulations and predictions. This image forces a clear link between supermassive black holes and the engines of bright galaxies. We now know clearly that black holes drive large structures in the universe from their home in the galaxy. We now have this highly new way of studying black holes that we've never had before, we have discovered, this is just the beginning. The imaging of black holes doesn't come easily, I can tell you that from personal experience. It is requiring long-term developments, a committed team, but also some very interesting cosmic coincidences, take for example the hot gas swirling around the black hole, photon has to leave from the horizon, travel through the hot gas to the blackhole, and the light rays of a millimeter length length, then that has to propagate 60,000 years through the galaxy, and another 55 million years to intergalactic space. Then it winds up in the Earth's atmosphere where it's greatest enemy, the greatest danger is that it'll be absorbed by water vapor in our own atmosphere. The telescope allows us to see what has traveled to us so far. But, the M 87 shadow is very small compared to the galaxy that surrounds it. In order to see it, we need to build a telescope as large as the earth itself. To do that, we use a technique using very long baseline interferometry. Radio waves from the blackhole hit radio telescopes, where they are recorded with the position of atomic clocks, with only one second every 10 million years. When you register these radio waves so precisely, you can store them on hard drives, send them to a central facility where they can be

combined precisely, it is exactly the same way that a mirror uses optical telescope reflected by perfect synchronicity to a single focus. When we do this, we can synthesize a telescope that has the resolving power, until we had on the size of the distance between these telescopes, truly turning the earth into a virtual telescope. All of the sites that we use can be seen here. We have telescopes from Hawaii, Arizona, Mexico, Chile, the South Pole, and even these, even this broad global network is not enough by itself to make an image. They can be silvered spots in a large area, the key is that the earth turns. We are able to sweep out more baselines, more coverage of this virtual mirror to make our image. On the left, you will see the earth turning, the repair of telescopes provides us with one point on the center panel, and on the right you can see the evolving image. The more data we get, the more we fill in this virtual mirror, the sharper the view of the blackhole becomes. So, we have taken advantage of a cosmic opportunity, it is remarkable when you think about it, light that left near the event horizon traveled all the way through intergalactic space and hit our telescopes. The earth just happens to be the right size so we get resolving power so that we can see the blackhole and M 87, and then the earth turns to fill in the mirror so that we can make this image. It is truly remarkable, it is almost humbling in a certain way. We are four members of a large collaboration, it is our distinct honor to be here to represent that collaboration. We are 200 members strong, 60 institutes, and we are working in over 20 countries and regions. We consider ourselves to be explorers, so the international cooperation and innovation, we have exposed part of the universe that we thought was invisible to us before. It is our responsibility to report these findings and we are doing that today to the National Science Foundation to our funding agencies, international and foundations, and to all people who support research, and also to the taxpayers. Nature has conspired to let us see something that we thought was invisible and we find it tremendous, and we hope that you will be inspired by it, too. Thank you, he has literally gone to the ends of the earth to collect some of the data we see here today.

[Applause]

Thank you. The heart of our measurement, it would have been an expensive and enormous undertaking just to do this experiment, instead we built an international partnership that allowed us to use telescopes are over the world, to make this measurement one that none of them could have done on their own. When you take a heterogeneous collection of telescopes and bill them into one giant telescope, it provides a lot of technical challenges. In the years leading up to our experiment, we went telescope by telescope all over the world, installing the specialized hardware we needed to do this. Most had detectors we could use, but almost none of them had the atomic clocks we need, and certainly none of them had the data recorders that we use. Some places, we had to do even more, a good example is the Oma telescope in Chile, it is a 66 telescope array, by far our most sensitive telescope. But, in order to use it, we didn't just need the basic hardware, we also needed a special piece of hardware that can some the light from all the telescopes before we send it to our reporters. This alone was a many year project using an international collaboration of people. Another good example is the South Pole telescope. The South Pole is a special place, it is so far south that it doubles the resolution for sources it can see. But, the SBT was designed to do a completely different kind of measurement, so it's detectors are not the detectors we need. So in addition to bringing down an atomic clock and all of the hardware that we needed, we had to build a special receiver that would detect the light we needed, special optics

to relay the light, and install it and get it to work in the cold and sometimes harsh Antarctic environment. This was many years of work for many of us, many trips down for myself and graduate students, and other engineers, but at the end of it, we had a telescope that could be in the station. Getting the site to work isn't the end of the process, we also had to test them all because you really only get one shot, everything has to be working exactly right when the script starts. So, we spent years taking site by site, pairing them up and making sure that the observations would work, the last of these observations was in January 2017, by March 2017, we knew that it worked, and we were ready to go. The image that he showed was from April 2017, from that campaign, we sent our team to the telescopes all over the world, their job was to turn everything on, do very extensive testing, and then be there to do the observation. But even with all of that in place, we still had to wait for the weather. And my experience with 10 years of doing these observations is that the weather is usually the place where we fail, we have to have good weather in Hawaii and Spain at the same time, and Arizona in the South Pole, that is a lot to ask. In 2017, we were very lucky. The first three days of observations were some of the best weather we have ever seen. For our 10 day campaign, we had taken all of the data that we wanted. At the end of that, it was recorded on more than 100 of these modules, and it amounts to more than half a ton of hard drives. It is a lot of data. It is equivalent to 5000 years of MP3 files, the entire selfie collection over a lifetime for 40,000 people. [Laughter] the image you saw isn't that in size, it is a few hundred kilobytes, so our data analysis has to collapse this data into an image that is more than 1 billion times smaller. We do that in many steps, the first is to get these modules to our core leaders in Massachusetts and Germany. The fastest way to do that is to put them on planes, there is no Internet that can compete with the data on a plane. Once they are there, their job is to find the exact same wave front of light arriving from the black hole at each telescope. Once it found small timing corrections that is lining up those waves, we can condense our data, we can average it, and read reduce the volume by 1000. But, we have a lot more work to do, the data still has imperfections, both from the instruments themselves, and the atmosphere above the telescopes. We do something called fringe fitting, we do this in the cloud with cloud computing which lets us do it in days, instead of weeks. We calibrate the data so that we know exactly how bright our sources are, and I'm speaking of this as though it is just computer work, but this is a very significant project for a subset of our team, primarily junior people, postdocs and graduate students, they deserve an enormous amount of credit for their diligence and dedication. Once we are done with that, we can finally go to the imaging stage. Now, imaging isn't as simple as downloading a picture from the camera. Fortunately, the mass that we use for it has been around for more than 200 years, the principal is well understood. The message, as with everything of this project is a little tricky for the data, in order to get the image, there has been years of image algorithm development that has been essential to our results. At this point in history, we have many different images to choose from, they have many different strengths and weaknesses, it just depends on the character of the data. We set up for teams all over the world, they are collaborating, each team is represented many parts of the world, and we told them, don't talk to each other or anyone else, choose with whichever algorithms you think are best. Then, in the summer of 2010, we brought everybody back together, as a very exciting meeting, the imaging workshop in Massachusetts. If you couldn't be there, you certainly called in from the Internet because he wanted to see the presentation. And a very exciting presentation revealed to the other teams into ourselves what we have found. And what we saw in those images were four very similar pictures, looking almost exactly like the one you see today. And in the midst of a ring surrounding the black hole. I'm glad that after a few more months of very careful

checking that we are finally able to share with you today. I would like to hand it off to my calling to talk about the interpretation.

Thank you, it is an enormous pleasure to be with you this morning for this extraordinary moment. We have now seen the unseeable, now what does it mean? In these first images, he began his journey embedded in the most extreme environment in the universe, the black hole, and in 87, in which these photons were born, it was empowered by the black hole in two distinct and related ways. First, a violent disc of orbiting gas driven inexorably toward the event horizon, by the time the material was making its final plunge in crashing into itself at nearly lightspeed, transforming the gas into 100 million degree plasma. Second, through astrophysical jets, beams of outflowing material speeding away from the black hole at nearly the speed of light. These jets are powered by black hole spins, rotating everything about themselves, driving these paradoxical structures. And, M 87, one of these is pointed towards us, the images are influenced both by these bright regions, the rotating disk and outflowing jets and by gravity itself. Radio waves fall just as apples do, typically this effect is exceedingly small, but black holes gravity run amok. They orbit the blackhole before beginning their 55 million your journey towards us, this results in the dark silhouette cast by the Verizon -- horizon. The portly, the size and shape of the shadow is determined by gravity alone. General relativity makes a clear prediction for both of these features. Within 10%, the shadow should be circular. With the diameter determined solely by mass, multiplied only by fundamental constants. However, as with all discoveries, when we began this expedition, we did not know what we would find. Where Einstein was wrong, the heart of the M 87, not a black hole, the silhouette could have been very different. Or misshapen or midsized, or even simply missing. Changing gravity changes how light bends, and thereby changes the shape of the shadow. In April, 2017, this was the dog that did not bark the shadow exists, it was merely circular, and the mass matched the estimates to the dynamics of stars 100,000 times as far away. The shadow is surrounded by a bright ring of enhanced emission to those photons that just escaped the blackhole's clutches. The properties of this ringlike feature result from the astrophysical drama that unfolds on gravity's stage. To understand these dramas, over the past 3 years, the DHT collaboration has undertaken an unprecedented simulation effort at research institutions across the globe. This is generally the largest collection of simulations ever assembled of the flow and jet launching region in M 87. The brightness arises directly from near light speed rotational motions near the black hole. The regions that moved toward us at nearly the speed of light are bright. Those that are moving more slowly or away are dim. From these, we have inferred the sense of rotation from the blackhole. In M 87, the blackhole spins clockwise. Moreover, the excellent quantitative agreement between DHT images and generic theoretical expectations of a bright crescent like feature with the dark interior provide significant consonants in our interpretation. The object of the heart of a mini seven -- M 87 is the blackhole like those described by general relativity. In combination with optical flux measurements, we can rule out a dim and otherwise visible surface, that is, this does appear to have the defining feature of a black hole. The event horizon, that point of no return. Today, several complementary windows have opened upon black holes, science fiction has become science fact. Today, two of these windows, the DHT, and the Lego -- knowing black holes are all consistent with a single description, black holes big and small are analogist in important ways. We have learned from one, necessarily applies to the other. At this point, I would like to hand the story off to Sarah who will describe the broader astrophysical implications of these images. Thank you.

[Applause]

Thank you, the black holes might be the most complex object, but they have a lot of consequences of their own, which I'm going to talk about today. That is because black holes are major disruptors of the cosmic order on the largest scales in the universe, they are helping mold to the shape of galaxies and clusters of galaxies. We have now confirmed, as Avery was saying, the general relativity itself does not change when we look at different blackhole masses, it turns out the impact of a black hole will actually change a lot, so we want to understand the role of black holes in the universe, then we need to have accurate determinations of the blackhole masses. This has been a problem up until now. So, our determination by just directly looking at the shadow has helped resolve a long-standing controversy in measuring the mass of M 87, there are two independent masses, one is basically looking at the motion of gas or stars, but they ended up getting different answers. Our determination of 6 1/2 billion solar masses lands right on top of the heavier mass determination of motion, this will help resolve the discrepancy that can lead to better mass determinations for other more distant black holes than we can actually see the shadow. So, getting to the impact of this is important because M 87's huge black hole mass exit and monster, even by supermassive black hole standards, you're basically looking at a supermassive black hole that is almost the entire size of our solar system. And part of the fact that we can see it, even though it is so far away, if we zoom back out to the more cosmic perspective, the galaxy is made of billions of solar systems, so on those skills, blackhole itself is minimally small, it is about 100 million times smaller than the galaxy. If it were a dormant blackhole the supermassive black hole in the center of our own galaxy, then the galaxy would have no way of knowing it is there, it would basically be like a pebble in a shoe. But, when the blackhole is activated, by gravitationally capturing material, it starts to convert that fuel into other swarms of energy, with the efficiency that can be almost 100 times of nuclear fusion that powers stars like our Sun. They temporarily become the most powerful engines in the universe, and they go quickly from being a pebble in a shoe to a thorn in the galaxy, literally. In the most extreme cases, these jets can penetrate to the entire galaxy and well beyond. But, the power that is coming out, we can't see with our own eyes, so we understand that we have to look in other wavelengths, so we looked with telescopes across the electromagnetic spectrum. This is another very active blackhole system, it is a combined image, so you see in white from NASA's Hubble telescope, the elliptical galaxies in the center, and overlaying and blue is the radiowave from the National Science Foundation's very large array, and these radio waves have basically been tracing magnetic fields in space, so that tells us that these jets are enormous fountains of magnetized material that are being sprayed out from the blackhole, not the blackhole itself, but near the blackhole, nearly at the speed of light. As these particular jets are 100 million times bigger than the blackhole. If we add another layer, we are going to look from NASA's telescope, and these are extremely high wavelengths. It is embedded in a halo of hot gas, and we can use this information to calculate how much energy the Jets have to get through the material. What we find is that the Jets are carrying the equivalent of 7 billion supernova of energy deposited over one of these active cycles. So, these kinds of interactions are basically very important because the tiny blackhole on these scales is somehow launching these structures and managing to heat the gas to prevent stars from forming. The galaxies are growing, and we think it is through these types of interactions that black holes help shape the largest structures in galaxies, and make them look the way they do today. M 87 is much more modest but as you can see, this is also from Hubble, it is still managing to launch the magnificent jets, these are admitting across the

electromagnetic spectrum as well, we need this information to be able to fully understand the system. If we zoom out now to the cluster of galaxies scales, this is another combined image here, and we think this is telling us about M 87 blackhole's past interactions, really affecting the cluster scales on hundreds or tens of hundreds of millions of years. We always thought that black holes were behind these large structures driving these engines, but we never knew, now we have direct evidence of the root of these problems, and we can look at this and we can now start to make, start to understand the atomic level processes to see how these interplay and conspire to make these enormous structures that are basically affecting the universe. To capture all of this information, we need to combine our observations with the multi-wavelength spectrum, as you heard from Dan, there are a lot of public cities and observations, and we add to that with many facilities across the globe. This is similar to the campaign that was run, it is very important to combine signals from photons and particles, by doing this, we expect DHT is going to play an active role in this new era of multi-messenger astronomy. Looking to the features, the same observations we took in 2017 for the M 87 also included this dormant blackhole. And by looking at two black holes with extremely opposite energy, we can better understand the flow of the influence of black holes in the long course of our history. Anyway, thank you very much, I'm going to hand this back over.

[Applause]

Thank you everyone, I just want to point out that when we first started the event horizon telescope project, the group was small and I think it had to be small and nimble to carry out precursor experiments and develop the first kinds of techniques that enabled us to move the field forward. But, over the past decade, the accomplishment has been in the building of a team, more than 200 people strong, many institutes over 20 countries and regions. If you want to reduce the data, if you want to develop new imaging algorithms, if you want the image of a black hole, then you need a large team. It has included many early career scientists, senior scientists, and many of them were here with us today. I would like to ask everybody who is associated with the event horizon telescope to please stand up so everybody in the media can see who has done this work.

[Applause]

It is a true pleasure to work with this crew. I also want to say something in particular about funding and support, this has been a high risk but high payoff endeavor, sometimes you have to kiss a lot of frogs before you get to the Prince, before you get to the blackhole image. You need supporters and funders who will stand by you, who understand the basic science and who also understands that you never know when it will pay off, but ultimately it usually does, and you have to play the long game. We have wonderful partners with the National Science Foundation, our international funding agencies and foundations and our hat is off to them for sticking by us for so long, and we look forward to greater things as we continue to sharpen our focus on black holes. Thank you.

Thank you very much. One note, some of our panelists and many of their collaborators were here this week in a documentary that has followed efforts of the DHT for the past 2 years. The film will show viewers how his team reached the groundbreaking moment, it is called blackhole hunters and it will premiere this Friday, April 12 at 9 PM Eastern on the Smithsonian channel. Please raise your hand, wait for a microphone, and identify yourself and who you are with you for asking a question.

The Associated Press, two part question, please, first, this is M 87, you have two targets initially, have you seen anything, have you captured any images of Sagittarius A yet and have not released them for whatever reason? Or have you not gotten those images? Second, one of the keys I understand, when you look at this distinct edge of the photon ring, not aside, this looks very fuzzy, is this distinct enough to notice the effect of gravity or not? How close is it to whatever measurement you use for sharpness of the edge?

I will start off with the first part, it is also very interesting of a target, we can see the event horizon, we should be able to resolve it. It is complex. M 87 was in some sense the first image, it is an easier image because of the timescale, it doesn't change much during the course of an evening, so we are very excited to work on the Sagittarius star, we are doing that very shortly, we are not promising anything but we hope to get that very soon. On the point about the circularity of the image, I would like to have Rita answer that.

Your question was on the sharpness of the edge. So, we have actually spent a considerable amount of time trying to upsize the particular details of this ring of light feature, and the sharpness, it falls off in less than 10% of the radio, that is the resolution that we have. Insofar as we can tell, it drops off nearly instantly.

Hi, I'm Alan with the choir -- GeekWire, are there things you might be doing to enhance further the quality of the image? Might there be more telescopes added to the network, or are you using different data processing techniques to get an even sharper image?

I will answer the first part of that, we think we can make the image perhaps sharper through algorithms, but we are embarking on a wonderful new series of putting new telescopes from places on the earth, so if you add more telescopes, you build out that virtual mirror, and even adding two or three more stations in just the right places will increase the fidelity of the image a lot. The other thing I would add, if you have higher frequencies, which the DHT is going to do soon, then you get an even higher resolution.

I think the biggest improvement it'll make would be through adding telescopes, and the higher frequency observations will be very exciting. As I said, in my section, the methods of imaging are



complicated. So, depending on what you are interested in, if you're interested in the sharpness of the ring, you can approach the imaging process slightly differently and make a less blurry looking picture.

Thank you very much. You said in your opening, that this was seeing the unseeable, I'm just wondering for a moment, as a scientist, what you, what your team members, what it felt like to see that image for the first time. Did you have a party? Did somebody cry? It is an amazing achievement, how would you really describe that?

That is a great question, we have been at this for so long, there was such a buildup, there was a great sense of release, but also surprise. When you work in this field for a long time, you get a lot of intermediate results. You could have seen something that was unexpected, but we didn't see something that was unexpected, we saw something so true, we saw something that really had a ring to it. [Laughter] and it was just astonishment and wonder, and I think any scientist in any field would know what that feeling is, to see something for the first time, it is a part of the universe that was off-limits to us. When that happens, it is an extraordinary feeling.

I will just add, as an astrophysicist, this is the first time that I thought it appear different to my eyes, this is a very big deal, I didn't really know what to expect. It is amazing. Congratulations.

You mentioned just now that this was kind of the perfect image, there wasn't really any surprises to it, it was the exact ring that you expected from general relativity, was there anything about it at all that was surprising or unexpected? Or was it just exactly what you were looking for?

As Avery said, it has verified Einstein's theory of gravity, in this most extreme laboratory. But, there are some very interesting things that we want to follow up with, there are asymmetries around the ring, the brightness in the southern part, so there will be a lot of future work on this to sharpen our focus on gravity.

So, first, I have to admit, I was a little stunned that it matched so closely be predictions that we have made. It is gratifying, sometimes frustrating. But, this is the beginning, we are asked about how we feel, I think it is a cathartic release that finally things are working, but also the anticipation and the amazing science that we are going to do by studying this image closely, and by repeating the experiment. In that sense, we will be able to improve the precision with which we can probe the area, and we may find scientific surprises.

Thank you for releasing the papers alongside the images, the first image on the paper there shows four different images from four different days, and it seems there are changes from day today, are those real? Can you say anything about time variability at this point?

There are two sets of images, the earliest image shows those four preliminary images that I spoke about. Those differs slightly from the final answer partially because that was still in engineering data release, it wasn't the final data. From day today, we have tried to establish how well we can trust the differences between the days, they seem real but at the moment, it is hard for us to interpret them. The timescale for variation from M 87 is very slow, so we hope that by looking at the data we got in 2018 we will be able to see if anything important has changed.

Can I add to that? The multi-wavelength is a key piece of the puzzle, so when we observed with DHT on a smaller scale, we also want to observe the multi-wavelength x-rays and the longer waves of radios on the larger scales, do you want to expand on that?

We actually highlight that in the first papers, and we did use information from the x-rays to help constrain some of the models but we have an enormous amount of multi-wavelength -- multi-length wave, M 87 was catching at adequate point, which we can tell from historical multi-wavelength, I think we just got lucky, had it been flaring, we might have seen something that would have blocked the hole as well. It might have been flaring even 7 years ago or so.

My name is Arthur, I'm a reporter, I have a general question about black holes, we are talking about the density and mass of the black holes, do you have any sense of the general length and width of the different black holes? Are we talking like billions of light-years across in terms of the with, or is it billions of miles? What keeps the density together in each blackhole? Do you think that larger black holes have a harder time keeping the density intact versus smaller black holes?

The answer to your first part of your question, how big is the blackhole? It is about 1 1/2 light days across. So, not light-years, it is measured in a day. It appears to evolve on weak timescales, so we see substantial changes, maybe two weeks, 1 1/2 weeks. What holds it all together? All black holes are the same, they are all about gravity. And, once you get that much mass collected into that smaller region, and how small depends on the mass, okay, so if I make it 10 times more massive, the reason I have to reach it is 10 times bigger. Once you have gotten that much mass that close together, gravity runs the show. And everything collapses down to the center, but behind the horizon, it is hard to reach. When you go there, you don't get to come back and tell us what you see.

I'm just wondering if these images can help with understanding how black holes are produced, and also, do you see this evolving over time or changing over time?

This comes back to one of the earlier questions. What we are seeing is effectively, when you look in different wavelength and also the fact that we are using a planet-sized telescope, we have the extreme precision to see the route very close to the blackhole, that region is all magnetized plasma, and it is effectively by squeezing the center and we are looking directly at this region, so we do anticipate this image, we haven't really begun to see the full analysis that we have done a lot of work so far, different groups within the team have been doing simulations and they assess the expectation of that that we will be making models and we will be comparing them again on the larger scale, and looking for variability. Looking for the underlying physics that is really going on. We have a pretty good idea in the broad stroke about what is happening. That is going to be the next step, I think you can expect quite a lot coming out.

Anna Humphrey, I was wondering, this is obviously an incredible feat of global collaboration in the scientific community, and do you see a model for science going forward? If so, what are the challenges and what are these the things we can hope to accomplish?

That is a great question. It is designed by its very nature of cross-border activities, we don't pay attention to where the telescopes are, just that they are high enough in command by scientists that share a common vision. In that sense, we built this team that is a 200+ member team by selecting experts from everywhere. I think it is a very good model for how we can do distributive science. We have published papers with people that we have never met before, but we consider them as true and trusted colleagues. That happens because we have the ability to reach out and form a distributed network of scientists. I think it is a good model.

Thank you for taking my question, I understand this is the enormous work of collaboration, but can you tell me more about the detail of each country's contribution? Specifically Japan.

I can say something about that, I work very closely with many people at the national Observatory of Japan and others. Japan has played a very key role, for example, Japan was one of the key members that made them essentially one dish, that can record on one set of equipment, that was huge. They have been a key partner in the imaging techniques. And pushing that forward, too. But, the key is that each country, each region, each group, each institute brought something in time, they brought their expertise and they brought their work. At the end of the day, you just need this stuff to get done. Everyone came with a full heart really, and the expertise and the energy to make this image that we presented to you today.

I was wondering, if nothing travels into the blackhole at the speed of light, other than light itself, how does the blackhole pull light into itself, I guess? And also, you have mentioned how the M 87 is 55 million light-years away, then how does the time work from capturing the light from here to itself?

It just takes light 55 million years to get here, so when we see M 87 in this image you saw, that is what it looked like 55 million years ago. That is the last part of your question. The first part, anyone?

So, light can't escape the horizon because in some sense, space-time itself is flowing through the horizon at that point, this is one of the beautiful elements of Einstein's theory of gravity, space is no longer a static stage on which things happen but you can think about it moving and flowing, and black holes drag it around when they spin and flows through the horizon even when they are static. So, those photons trying to climb out of the gravitational potential well, outside the horizon can do so because it can go faster. But, they are dragged in.

I want you to talk a little bit more detail in your future plans and give more detail about when and what you are looking at.

Well, I would point out that April 2017 we had eight telescopes in six geographic locations, and in 2018, we had another telescope which dramatically increased our coverage of M 87, and we are going to add a new telescope in Dan's backyard, in the Observatory in Arizona, these will increase the imaging fidelity's, they will fill out that virtual mirror that we are trying to build. That is important for something that Sarah described, which once the Jets. It is difficult for us to make a firm connection to the larger scaled Jets that Sarah showed. By adding more telescopes, it is intermediate and longer baselines will be able to extend the image of the shadow out to where it connects to that jet. That is one area that we are expanding into and the increased frequency of observations. We observed it with one millimeter wavelength, but it increases your angular resolution, the resolving power by over 30%. So, you wind up sharpening your image just by observing at higher frequencies. And then of course, world domination is not enough for us, we also want to go into space. If we can orbit around the earth and get even more of that virtual mirror, we can do it much more quickly.

We only have time for a couple more. Let's go right here.

Hello, Tom from NBC news, congratulations for all of you. I have a question for Sarah or Avery, both of you being such devoted scientists and devoting your life to this, what are your thoughts about Einstein, who predicted much of this so long ago, I wonder what your thoughts are about his genius today and what you verified.

Well, I do spend time thinking about how it is that somebody could have sat down in a patent office hundreds of years ago and come up with a theory that has turned into something, I mean, it is great that we can see it verified, but we use this everyday for satellite communication, it is very integral part of our

understanding in the universe, but to me, I feel like there are bigger mysteries afloat, I'm fascinated by Einstein and that level of understanding in the universe. There are many people thinking about this also, but I'm fascinated about black holes and quantum gravity, and how does gravity actually work? Is it some emergent process coming out of space-time? What is space-time? I think there is a lot more, it is just the beginning for me.

Sometimes the math looks ugly but really, there is a strong aesthetic, and the Einstein equations are beautiful. So often in my experience, nature wants to be beautiful, that is one of the striking elements about the Einstein equation, about this description of gravity. It is fundamentally one of the most beautiful series theories we have. For that reason alone, and the long history of Einstein being proven right here, as I suppose we are not terribly surprised that I can't lie to you, this is the most exciting thing we could possibly do, to find that in this extreme gravitational laboratory that there is something a little new, and as Sarah pointed out, history is abound around black holes. And we do know that there must be something more. The problem of quantum gravity remains unsolved with the current tools that we have and black holes are one of the places to look for answers.

Okay. Right here.

Hi, Michael, National Geographic, you mentioned seeing the unseeable, but I want to talk about another aspect of our universe, dark matter. Avery, you co-authored a paper in 2017, pointing out that M 87 in particular with the event horizon telescope would be a unique probe into dark matter, to the degree to which it annihilates its interactions with other patterns. Can you say anything at this point about how this measurement changes or constrains what we know about dark matter?

The quick answer is not yet. [Laughter] we have been very focused on making the first interpretation of this groundbreaking image, we have not yet gone to that particular topic.

Thank you all for attending, if you have further questions, staff from the National Science Foundation are here to help, also you have an email address inside your packet for any follow-up questions, thank you for joining us today, this concludes the live stream.

[Applause]